91502
new 82-10

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research If
Copied in Whole or in Part.

ontario hydro
research division

EXECUTIVE SUMMARY

CLEARANCES FOR GALLOPING ON OVERHEAD LINES

D.G. Havard, C.J. Pon and G.S. Watt
Applied Mechanics Section
Mechanical Research Department

The scope of field trials of promising devices for controlling galloping on single conductor transmission lines is outlined and key data usable in probabilistic analysis are presented. The variation of clearances for avoiding flashovers due to galloping in a representative transmission line are given. The probabilities of galloping occurring at amplitudes which exceed the clearance are determined for single conductors without control devices and with detuning pendulums. It is shown that the probability of flashovers without pendulums is about 1000 times that when detuning pendulums are used. At present, operational data are not sufficient to calibrate the predicted flashover probability values. Further research on a method of predicting galloping outage probability is warranted.

job	file	date	report no.
740621-302-431	825.151	October 14, 1986	86-233-K

91602
new 82-10

To: Dr. D. Mills
Director of Research

ontario hydro
research division

CLEARANCES FOR GALLOPING ON OVERHEAD LINES*

D.G. Havard, C.J. Pon and G.S. Watt

The scope of field trials of promising devices for controlling galloping on single conductor transmission lines is outlined and key data usable in probabilistic analysis are presented. The variation of clearances for avoiding flashovers due to galloping in a representative transmission line are given. The probabilities of galloping occurring at amplitudes which exceed the clearance are determined for single conductors without control devices and with detuning pendulums. It is shown that the probability of flashovers without pendulums is about 1000 times that when detuning pendulums are used. At present, operational data are not sufficient to calibrate the predicted flashover probability values. Further research on a method of predicting galloping outage probability is warranted.

INTRODUCTION

Conductor galloping of overhead lines is due to wind blowing across the conductors when they carry a coating of ice. The resulting motions are large amplitude, low frequency oscillations primarily in the vertical plane. These motions can result in repeated contact and flashovers between the conductors, particularly on vertically aligned circuits, leading to burnt conductors, overloaded breakers and interruption of the power supply. The motions also produce wear and fatigue of hardware components requiring additional maintenance. Designers of overhead lines usually include allowances beyond the clearances

---

* Report originally presented as a paper at the First International Symposium on Probabilistic Methods Applied to Electric Power Systems, Toronto, June 11-13, 1986.

required for electrical insulation and safety of linemen, or to limit span lengths, to accommodate these galloping motions and so limit the impact of galloping on the system operation.

This paper presents recent results of large scale field experiments with a number of promising galloping control devices on operating lines. An attempt is made to analyze these results to enable them to be used in the line design process. The paper indicates the manner in which design codes for overhead lines could be modified to include the benefits of these devices in a realistic manner. It appears possible that, using control devices now being studied, future lines may be built with longer spans or shorter towers than present practice, without reducing reliability, and with considerable savings in capital cost. In addition, lines with galloping controls can be expected to require less maintenance due to less severe motions.

FIELD TRIALS OF GALLOPING CONTROLS

An earlier paper (Pohlman and Havard, 1982) presented a review of the field research on effectiveness of various devices to control galloping. That paper described the cooperative program in which promising devices are installed on operating lines of utilities in Canada, the United States, Japan and Europe. These are observed by trained utility staff who prepare written and movie filmed reports of any galloping motions. The results obtained from these field trials were described more recently (Havard and Pohlman, 1983). That paper showed that for a large range of sizes of single conductors, use of detuning pendulums (Nigol and Havard, 1978) was found, using rigorous statistical evaluation, to be effective in reducing galloping amplitude by a significant margin. Using an empirical analysis of an extensive data bank of observations of galloping on lines without control devices (Rawlins, 1981), this reduction was found to be about 75% of the maximum amplitude expected.

Results obtained since that time continue to confirm this conclusion and also indicate support, but without the same level of confidence, for the use of detuning pendulums to control galloping on bundle conductor lines. Other control devices show promising results; notably the air flow spoiler (Whapham, 1982) on the smaller sizes of conductors normally used on distribution lines. This paper makes use of the field data available from observations of performance of detuning pendulums on single conductors because these have the largest data bank of all control devices. The approach to interpretation shown here would be applicable to data banks from other devices once they are sufficiently large to statistically verify the general applicability of the results.

A representative detuning pendulum used on single conductor transmission lines is illustrated in Fig. 1. These pendulums are rigidly clamped to the conductors at several points within the span and are designed to modify the torsional natural frequency of the conductor so that it remains more separate from the vertical natural frequency under icing than for a normal untreated conductor.

RESULTS OBTAINED

The previous analyses (Havard, Paulson and Pohlman, 1982; Havard, Pon and Pohlman, 1985) used the total data bases available from galloping observations of both single and bundle conductor lines with detuning pendulums. That approach permits comparison of total data bases for detuned and reference conductors to give the overall assessment of effectiveness. However, the most critical problem due to galloping is the extreme value of the motions which can cause flashovers between conductors when the clearance is inadequate. Consequently, it is most important to be able to predict the maximum amplitudes to be expected on a line, with or without control devices, within a given period of operation. For this study the data bases have been reduced to the extreme values reported during each observation. This then allows use of the extreme values distribution to predict future occurrences and their frequency.

A galloping observation may vary from just one value of estimated motion on the reference and on the treated conductor in one span to a report of motions on ten or more spans of up to four circuits. Also the report may be from properly trained observers, perhaps backed up by movie film records, or from other staff who happened to be in the area during the event. Consequently, there is a very uneven quality to the data bank. It cannot be compared to systematically collected data using established routines, such as is normal in, for example, weather reporting.

The data used in this analysis are from single conductors and are presented in Table 1. These results are for conductors between 25 and 50 mm (1 to 2 inches) in diameter in spans between 100 and 400 m (300 and 1200 feet) in length, with properly installed detuning pendulums. The total data bank comprises 528 data pairs from 25 observations, which is the largest bank of data for any device. For each observation the maximum values of peak-to-peak galloping motion on the reference and the detuned conductors within the test site are given. The representative sag under 12.7 mm (1/2 inch) of ice load and 129 Pa (2.7 psf) wind load at 0°C is also given. This will subsequently be used to relate the

results of the analysis to design of clearances to avoid flash-over due to galloping.

The single conductor galloping data are presented in a three-dimensional plot containing paired maximum data in Fig. 2. The amplitudes are scaled by dividing by the sag in an effort to normalize to a common base as well as to permit the results be related to design practice. Each pair of observations is plotted within the figure as a vertical block on the base plane. The figure permits subjective interpretation of the results from the location of the blocks, their distance from the origin and their height. The location of the blocks indicates degree of control. Data along the left hand axis indicate the devices cause galloping; data along the centre indicate no effect and data along the right hand axis indicate perfect control. Data near the origin are from modest amplitudes of galloping motion while those remote from the origin are from worst storm cases. The heights of the blocks are proportional to the number of results and so relate to the confidence in the overall applicability of the trends.

The results for single conductors shown in Fig. 2 show clustering along the right hand axis showing generally good control. The extreme values on the reference conductors are up to 1.50 which is slightly above the highest nominal galloping factor of 1.4 used in Ontario Hydro. This indicates that severe galloping is included in the sample. The maximum amplitude recorded on the detuned phase is 0.38.

ANALYSIS OF GALLOPING FIELD DATA

The extreme values from these observations have been analyzed to permit estimates of less frequent occurrences to be obtained. The technique used is the application of Weibull's extreme values distribution (Gumbel, 1954) which allows the required extrapolation. The approach is used for predicting occurrences of natural extreme events such as flood water levels and high winds. It has also been used to estimate wind and icing loads on overhead lines for the application of probabilistic design techniques (Krishnasamy, 1985).

The field data from single conductors with no galloping controls are presented according to this distribution in Fig. 3. The field data have been normalized using the sag and then placed in ascending order. The values of galloping amplitude divided by sag are then plotted against the percent of the number of data points plus one on the cumulative plot of the distribution as shown. The figure shows a reasonably linear plot supporting the

use of this distribution. The trend through the data is obtained from the best fit straight line. The graph also includes upper and lower confidence limit lines which should include 90 percent of the individual observed values. These lines permit the frequency of galloping reaching a particular level in relation to the sag in similar terrain and weather exposure to be estimated.

Fig. 4 shows the same data and fitted distribution curve in noncumulative form. In this figure the tail of the distribution indicates that there is a small but finite probability of occurrences beyond the observed field data, and this can be estimated using the extreme values distribution properties.

The data for single conductors with detuning pendulums are presented in similar plots in Figs. 5 and 6. These figures follow the same trends as those for the untreated conductors, but at consistently lower amplitude levels. It should be noted that the pairing of the field data is lost in this method of analysis. That is, the highest amplitude on the treated conductors does not necessarily correspond to the highest on the reference conductors.

GALLOPING CLEARANCES ON ACTUAL LINES

When a tower is designed for a particular line, the design span for galloping clearances is based on the maximum normal span length. Terrain conditions, such as lake or river crossings, may dictate that a small number of spans exceeds this value. Also some spans may be considerably shorter to suit local requirements of the right of way. However, most of the span lengths will be close to the design span. The galloping factor, that is the ratio of the galloping clearance ellipse length to the sag, will then vary from span to span along the line. This factor has a nominal value that corresponds to the security level required in the line. For the spans that are close to the design span in length this will be a reasonable representation of the security. But for the spans that are shorter or longer, the galloping factors have greater differences because the sag depends on the square of the span length.

For the purpose of this paper the span length distribution of a representative line in South West Ontario will be used. This line runs in a North-South direction and comprises 201 spans with a ruling span of 226 m (740 ft). The span lengths range from 131 m (430 ft) to 364 m (1195 ft). The galloping factor corresponding to the ruling span for this line is 2.0 which is well above the values of 1.0 to 1.4 which are nominal minimum values

for most transmission lines in Ontario. A design span of 427 m (1400 ft) corresponds to the normal galloping factor of 1.2 for this line. The distribution of galloping factors throughout this line is presented in Table 2 and in Fig. 7. The distribution shows a sharp peak at a value of 2 with tails to 0.7 on the low side and to nearly 6 on the high side.

PROBABILITY OF FLASHOVERS

Field observations of galloping are characterized by noticeable variations in behaviour of individual phases and spans and from time to time during the icing storm. There appears to be no clear relationship to the exposure or weather condition to account for these differences. This random nature is an inherent feature of galloping and must be recognized in any attempt to assess the probability of flashovers due to galloping motions. Any of the spans in the representative line can experience the least or most severe galloping motions. The occurrence of flashover is indicated when the galloping motion, as shown by Fig. 4, exceeds the clearance as shown by Fig. 7. These two curves are on directly comparable scales and it can be seen that there is a finite region of overlap corresponding to a small probability of flashovers occurring. The frequency of outages represented by this overlapping region is calculated as follows. Any combination of galloping factor and normalized amplitude of galloping can occur with the probability that is the product of their individual probabilities. The product of those combinations resulting in flashovers, as a fraction of all products, is the relative probability of flashovers occurring.

Figure 8 shows this diagramatically. The probability distribution of the galloping amplitude, as plotted in Fig. 4, is used as the ordinate. The distribution of galloping factors along the line, which represents the available clearance for galloping motions, as plotted in Fig. 7, is the abscissa. Each area within the figure is the product of the probabilities for each combination of galloping amplitude and clearance. The darkest shading indicates the combinations with highest probability. The diagram includes a diagonal line through the origin which separates the figure into two regions. To the left of this line the galloping amplitude is greater than the clearance and so conductor clashing and flashover can occur. To the right of the line the clearance is greater than the galloping motions and no flashover problems would be expected. The sum of the probabilities to the left of this diagonal line, given as a fraction of the total, is the probability of flashover of any span of this line section during one ice storm. For the untreated spans represented by Fig. 8 this probability is 1.1 percent.

A similar analysis has been performed using the field data from single conductors with detuning pendulums. The results are presented in Fig. 9 using the same layout as Fig. 8 to permit direct comparison. It can be seen that the addition of pendulums has reduced the occurrences of flashover conditions, that is plotted areas to the left of the diagonal line from the origin, to almost zero. The calculated probability of flashovers from Fig. 9 is 0.001 percent. That is a reduction by a factor of about 1000 in the probability of flashovers on this line due to the addition of pendulums.

The above analysis for untreated lines can be compared to operating records for calibration of the process. The 1.1 percent probability of one span flashing over in each ice storm suggests that there would be 1.1 x 201 percent probability, that is 221 percent, of any of the 201 spans flashing over in an ice storm. The actual operating records shows no outages on this line during the past 15 years although galloping has been observed frequently at amplitudes that do not cause flashovers. It should be noted that the data base on single conductor galloping is from sites with known histories of galloping and so represents a sample biased towards more severe galloping behaviour.

The time scale for these probabilities is quite indistinct. The data base of galloping observations covers a period of 10 years on 7 separate lines. However, it is most likely that the observations do not include all galloping occurrences. Also some of the test sites were under observation throughout the period but others were developed more recently. For the purposes of the discussion here, the unit of time will be the average period between ice and wind conditions that cause galloping on a given line. The regional variation can then be factored in based on past weather data.

Operating records from lines in a given area provide some indication of its predisposition to galloping. These records tend to contain limited information as to the cause of outages and have no information regarding galloping at amplitudes below flashover causing levels. Nevertheless an attempt can be made to relate the predicted galloping outage rate for other lines with operating records which include flashovers due to galloping.

CONCLUSIONS

1. Using data available from field trials of galloping control devices and the variation of clearances within a representative transmission line, the probabilistic design approach

can be used to estimate the probability of flashovers due to galloping.

2. Comparison of predicted probabilities of flashover for single conductors with and without detuning pendulums shows that, for the line section studied, the flashover probability is reduced by a factor of about 1000 due to the pendulums.

3. Operational records of outages due to galloping on lines are very limited because the causes are not always clearly known. Application of this probabilistic approach to lines with known records of outages due to galloping is required to calibrate the predicted probability of flashover.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the considerable encouragement and assistance of Ontario Hydro staff, and the staff of companies and utilities participating in the galloping field trials in Europe through CORECH, in Canada through CEA, and in the USA through EPRI. This study would be impossible without the dedication of the field observers who have gathered the data on

the galloping motions of lines on which this analysis relies. To those many individuals the authors express their heartfelt thanks.

Approved by:

G.J. Clarke
Manager
Mechanical Research Dept

Prepared by:

D.G. Havard
Sr. Research Engineer
Applied Mechanics Section

C.J. Pon
Engineer
Structures and Transmission
Applied Mechanics Section

Approved by:

B.A. Oliver
Manager
Design and Development -
Transmission

G.S. Watt
Acting Supervising Engineer
Line Layout and Standards
Design and Development -
Transmission

DGH/GJP/GSW:am/sf

REFERENCES

Gumbel, E.J. (1954). Statistical Theory of Extreme Values and Some Practical Applications. National Bureau of Standards, Applied Mathematics Series 33.

Havard, D.G., A.S. Paulson and and J.C. Pohlman (1982). The economic benefits of controls for conductor galloping. CIGRE Paper 22-02, Paris, France.

Havard, D.G., and J.C. Pohlman (1983). Five years' field trials of detuning pendulums for galloping control. IEEE Paper 83 SM 470-2.

Havard, D.G., C.J. Pon and J.C. Pohlman (1985). Field evaluation of galloping controls for single and bundle conductor lines. CEA Conductor Vibration Workshop, Montreal, Canada.

Krishnasamy, S.G. (1985). Assessment of weather induced transmission line loads on a probabilistic basis. IEEE Paper 85 WM 234-0.

Nigol, O., and D.G. Havard (1978). Control of torsionally induced galloping with detuning pendulums. IEEE Paper A78 125-7.

Pohlman, J.C., and D.G. Havard (1982). Field research on the galloping of iced conductors - a status report. Proc. 1st Int'l. Workshop on Atmospheric Icing of Structures, Hanover, N.H., USA.

Rawlins, C.B. (1981). Analysis of conductor galloping field observations - single conductors. IEEE Paper 81 WM 038-9.

Whapham, R. (1982). Field research for control of galloping with air flow spoilers. Missouri Valley Electric Assoc. Conf., Kansas City, Missouri, USA.

TABLE 1: Galloping Observations on Single Conductors

Observation Number	Date	Utility	Test Site*	Peak-to-Peak Galloping Amplitude(m)		Sag With Ice & Wind (m)
				Untreated	Detuned	
S5	18/12/77	Ontario Hydro	Manby	6.0	1.2	4.7
S6B	18/12/77	Ontario Hydro	K-R	0.6	0.0	4.0
S14B	25/3/78	Comm-Edison	L2218-L2219	2.7	0.0	1.8
S15	26/3/78	Comm-Edison	L15913	0.0	1.2	3.5
S16	26/3/78	Ontario Hydro	Manby	1.8	1.8	4.7
S17B	3/12/78	Ontario Hydro	K-R	1.5	0.0	4.0
S21	24/1/79	Ontario Hydro	K-R	3.6	0.6	7.4
S26	22/2/80	Ontario Hydro	Manby	1.8	0.9	4.7
S27	22/2/80	Ontario Hydro	Manby	2.4	0.0	4.7
S28	22/2/80	Ontario Hydro	Manby	1.5	0.0	4.7
S29	22/2/80	Ontario Hydro	K-R	3.1	0.0	6.8
S30	22/2/80	Ontario Hydro	K-R	3.1	0.0	7.2
S31	22/2/80	Ontario Hydro	K-R	3.1	0.0	6.8
S32	22/2/80	Ontario Hydro	K-R	3.1	1.2	6.8
S33	22/2/80	Ontario Hydro	K-R	2.4	0.0	7.4
S34	22/2/80	Ontario Hydro	K-R	3.1	0.0	7.1
S35	22/2/80	Ontario Hydro	K-R	0.9	0.0	7.1
S36	22/2/80	Ontario Hydro	K-R	1.2	0.0	7.1
S43A	4/1/82	Ontario Hydro	O-M	1.8	0.9	9.1
S46A	2/2/83	Ontario Hydro	O-M	0.9	0.0	8.6
S49A	21/3/83	Ontario Hydro	B-H	6.1	0.6	6.2
S55	14/12/84	Ontario Hydro	Manby	2.4	0.9	4.7
S56	14/12/84	Ontario Hydro	Manby	1.5	0.0	7.4
S57	14/12/84	Ontario Hydro	N-M	0.0	1.2	5.7
S58	7/1/85	Ontario Hydro	Manby	2.1	0.0	4.7

*K-R is Kleinburg-Richview; O-M is Ottawa-Merivale;
B-H is Burlington-Hamilton Beach; N-M is Nanticoke-Middleport

TABLE 2

DISTRIBUTION OF GALLOPING FACTORS (CLEARANCE/SAG) ON A REPRESENTATIVE LINE

Galloping Factor	No of Spans	Galloping Factor	No of Spans	Galloping Factor	No of Spans
0 - .1	0	2 - 2.1	21	4 - 4.1	0
.1 - .2	0	2.1 - 2.2	22	4.1 - 4.2	0
.2 - .3	0	2.2 - 2.3	20	4.2 - 4.3	1
.3 - .4	0	2.3 - 2.4	13	4.3 - 4.4	1
.4 - .5	0	2.4 - 2.5	9	4.4 - 4.5	2
.5 - .6	0	2.5 - 2.6	8	4.5 - 4.6	0
.6 - .7	0	2.6 - 2.7	6	4.6 - 4.7	0
.7 - .8	1	2.7 - 2.8	1	4.7 - 4.8	0
.8 - .9	0	2.8 - 2.9	2	4.8 - 4.9	0
.9 - 1	1	2.9 - 3	5	4.9 - 5	2
1 - 1.1	0	3 - 3.1	3	5 - 5.1	0
1.1 - 1.2	1	3.1 - 3.2	1	5.1 - 5.2	0
1.2 - 1.3	3	3.2 - 3.3	2	5.2 - 5.3	0
1.3 - 1.4	3	3.3 - 3.4	0	5.3 - 5.4	0
1.4 - 1.5	2	3.4 - 3.5	0	5.4 - 5.5	1
1.5 - 1.6	5	3.5 - 3.6	0	5.5 - 5.6	0
1.6 - 1.7	4	3.6 - 3.7	1	5.6 - 5.7	0
1.7 - 1.8	4	3.7 - 3.8	2	5.7 - 5.8	0
1.8 - 1.9	5	3.8 - 3.9	1	5.8 - 5.9	1
1.9 - 2	47	3.9 - 4	0	5.9 - 6	0

FIGURE 1
DETUNING PENDULUM FOR SINGLE CONDUCTOR LINES

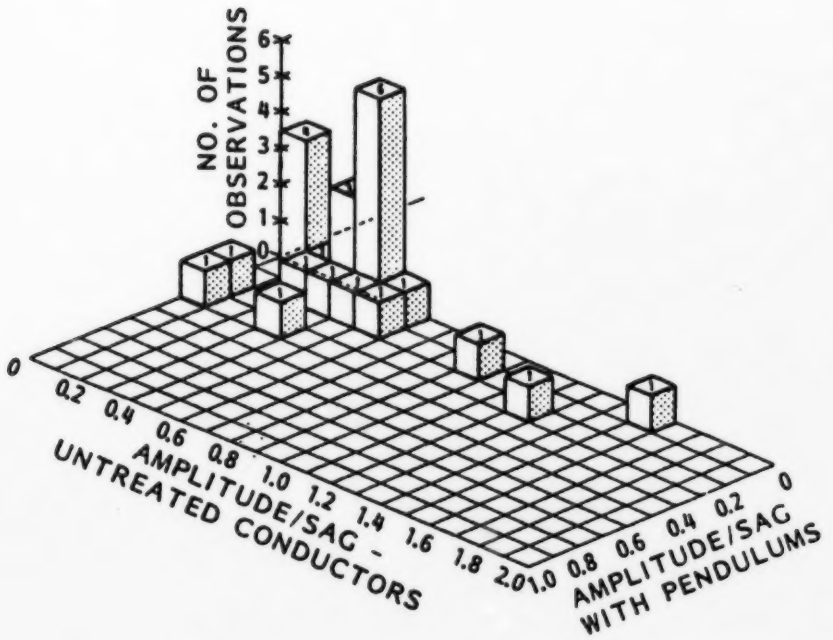

FIGURE 2

GALLOPING DATA FROM 25 OBSERVATIONS ON SINGLE CONDUCTOR LINES 25 - 50mm IN DIAMETER ON SPANS 100 - 400m IN LENGTH. COMPARING MAXIMUM AMPLITUDES OF UNTREATED CONDUCTORS WITH DETUNING PENDULUMS IN TERMS OF SAG AT 0°C.

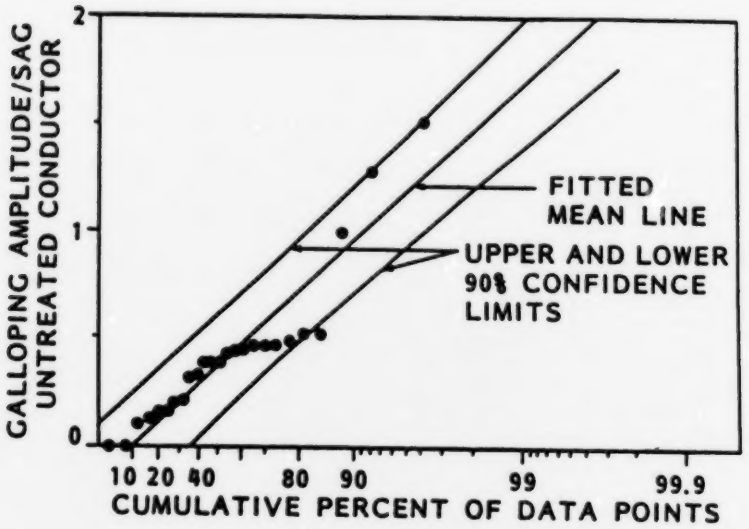

FIGURE 3

EXTREME VALUES OF GALLOPING AMPLITUDE
FROM SINGLE CONDUCTORS WITHOUT PENDULUMS.
NORMALIZED GALLOPING AMPLITUDE VERSUS
CUMULATIVE PERCENT OF OBSERVATIONS.

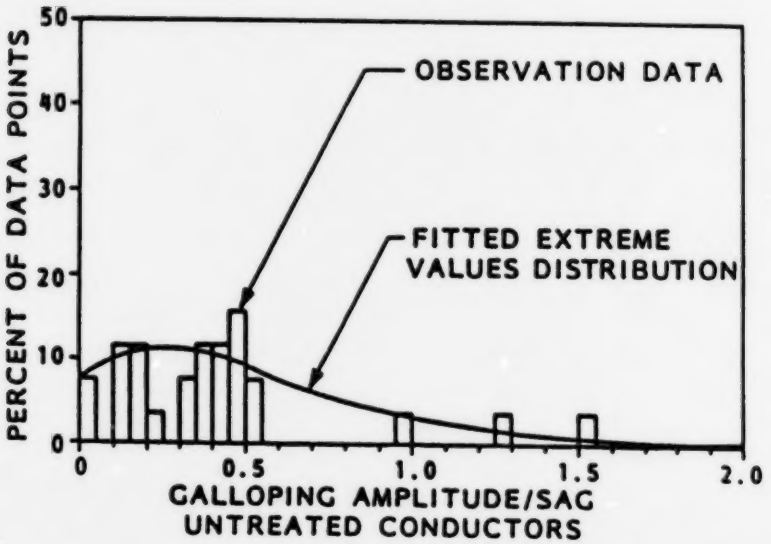

FIGURE 4

EXTREME VALUES OF GALLOPING AMPLITUDE
FROM SINGLE CONDUCTORS WITHOUT PENDULUMS.
PERCENT OF DATA POINTS VERSUS
NORMALIZED GALLOPING AMPLITUDE.

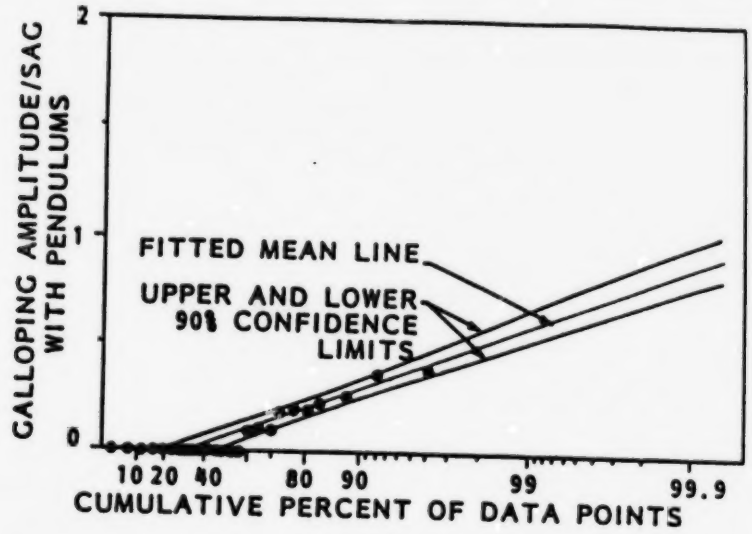

FIGURE 5

EXTREME VALUES OF GALLOPING AMPLITUDE FROM SINGLE CONDUCTORS WITH DETUNING PENDULUMS. NORMALIZED GALLOPING AMPLITUDE VERSUS CUMULATIVE PERCENT OF OBSERVATIONS.

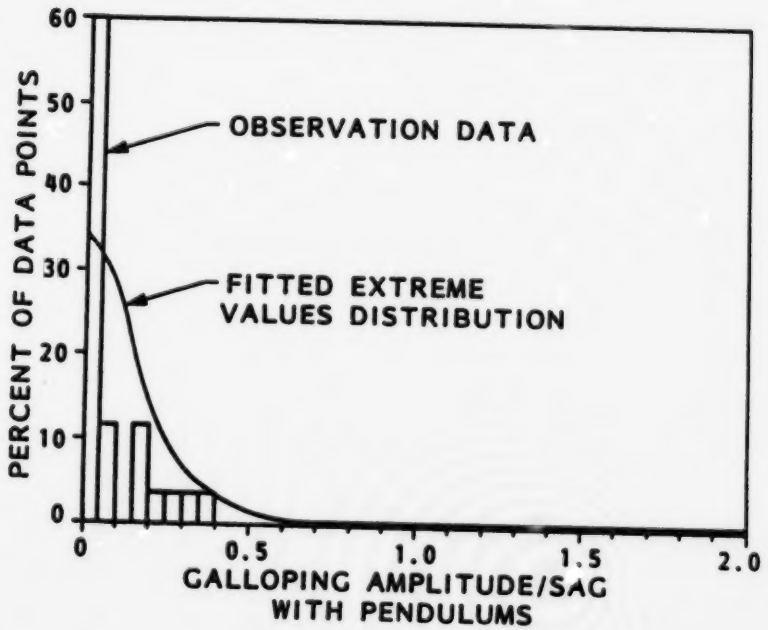

FIGURE 6

EXTREME VALUES OF GALLOPING AMPLITUDE FROM SINGLE CONDUCTORS WITH DETUNING PENDULUMS. PERCENT OF DATA POINTS VERSUS NORMALIZED GALLOPING AMPLITUDE.

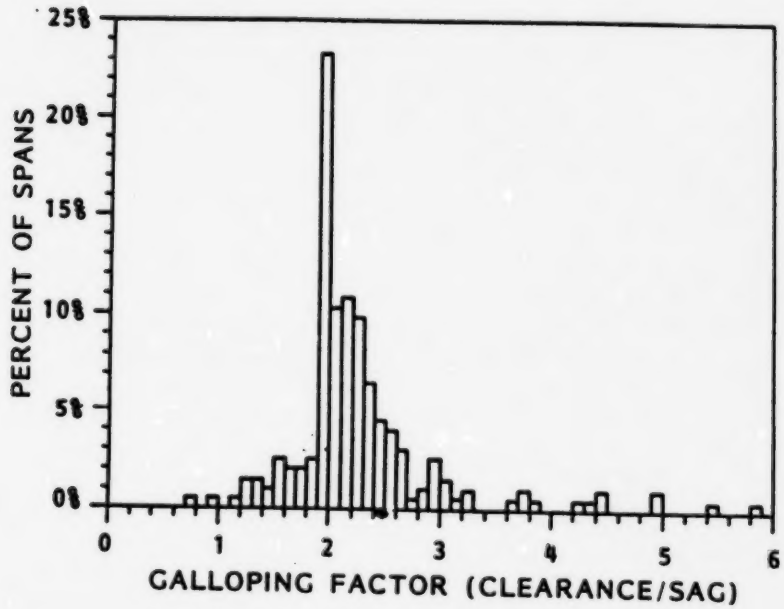

FIGURE 7

DISTRIBUTION OF GALLOPING FACTORS FOR
A REPRESENTATIVE TRANSMISSION LINE

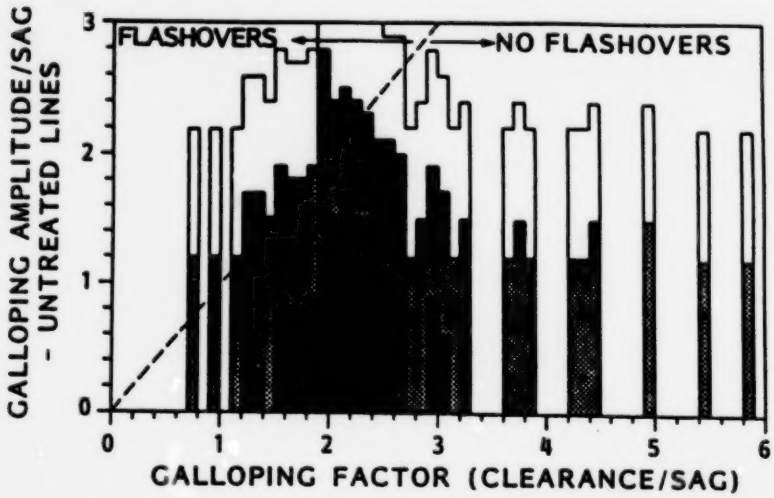

FIGURE 8

DISTRIBUTION OF PROBABILITIES OF GALLOPING OCCURRENCES ON UNTREATED SINGLE CONDUCTORS COMBINED WITH CLEARANCE ON A REPRESENTATIVE LINE

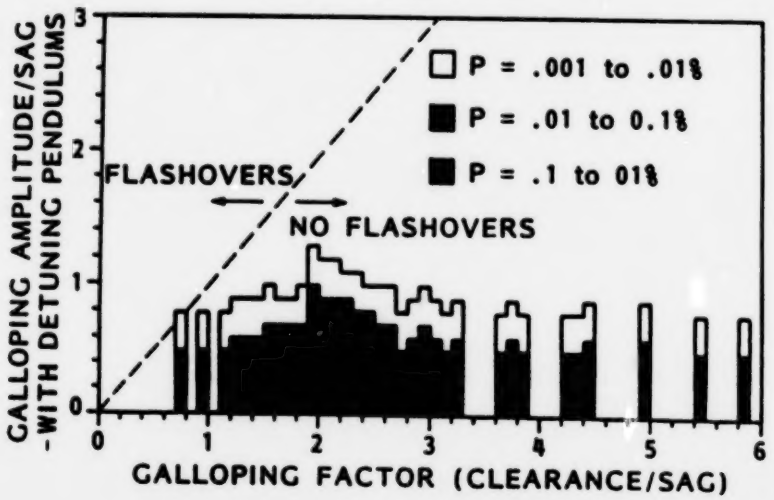

FIGURE 9

DISTRIBUTION OF PROBABILITIES OF GALLOPING OCCURRENCE ON SINGLE CONDUCTORS WITH DETUNING PENDULUMS COMBINED WITH CLEARANCE ON A REPRSENTATIVE LINE